

UARS Power System and Plasma Interaction

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Abstract

The Upper Atmosphere Research Satellite (UARS) has been operating since its launch in 1991. The UARS generates 1600 watts of power by solar arrays, one main and an auxiliary. The act of generating power causes the spacecraft to be charged. This charging level exceeded that predicted both in magnitude and duration. Charging adversely effects the lower energy plasma detector causing it to produce results which are inadequate for the production environment of UARS.

1. Introduction

Currently in operation, the Upper Atmosphere Research Satellite (UARS) has the charge of long term monitoring of the earth's upper atmosphere. The UARS spacecraft was launched in September of 1991 into a circular orbit at 585 km altitude. The orbit has an inclination on 57 degrees and precesses in local time every 34 days. Geographically, the spacecraft covers the globe in 16 orbits each day. The UARS system was designed to be clean, predictable, and stable in the long term so that science measurements made a solar cycle apart could be related with confidence.

The UARS spacecraft is constructed of a graphite-epoxy/titanium frame. This frame serves as the "optical bench" to which all of the science and engineering instruments are referenced. Most of the science instruments view on one side of the spacecraft while the opposite side contains many on the engineering instrumentation. Figure 1 shows the UARS spacecraft during its integration phase at General Electric, the spacecraft contractor. The view is from a position viewing at the side of the spacecraft which includes many of the science instruments.

2. Power System

The UARS power system generates 1600 watts of power from a combination of two solar array units which are co-located on the spacecraft. These units are called the main solar array and the auxiliary solar array. The main solar array feeds the spacecraft modular power subsystem (MPS), providing power for the spacecraft and its subsystems, the battery charging system, and the remainder is supplied to the payloads, see Figure 2. The auxiliary solar array output is feed directly to the payloads of science instruments. The main solar array generates about 1000 watts of power and the auxiliary solar array generates about 600 watts of power.

Physically the solar array is made up of intertwined silicon solar cells configured into six panels. Each panel is 1.25 inch thick, 128 inch long, and about 60 inch wide. When fully extended, the solar array panels are adjacent forming an area of 128 inch by 364 inch. This solar array is suspended on one side of the spacecraft and drive motors can rotate the array a full

360 degrees. Under normal operations, the solar array tracks the sun as the spacecraft moves through its orbit. Figure 2 shows the solar array in relation to the remainder of the UARS spacecraft.

3. Instrumentation

The instrument which is strongly influenced the most by the charge on the spacecraft is the Medium Energy Particle Spectrometer (MEPS). The MEPS instrument is part of the Particle Environment Monitor experiment (PEM) and consists of detection units located in eight different viewing directions with respect to the local zenith: -158.7 degrees, -23.7 degrees, 6.3 degrees, 21.3 degrees, 36.3 degrees, 66.3 degrees, 126.3 degrees, and 156.3 degrees. The five detectors located in the zenith direction (mounting angles <90 degrees) are mounted on the zenith boom of the spacecraft. Each detector has both electron and ion sensors which are multiplexed to optimize viewing direction, spacecraft location, and telemetry locations. The remaining three sensors located on the nadir spacecraft boom and contain only electron sensors.

Figure 3 shows a section of one of the MEPS detectors. Plasma enters the detector through the entrance aperture in the collimator and passes through the deflection plates. A voltage is applied across the deflection plates, causing an electric field in that region. Plasma particles which are charged respond to this electric field and their trajectory through the detector is altered. Particles which have a critical energy which is proportional to the voltage across the deflection plates pass between the deflection plate and light trap, entering the channel electron multiplier (CEM) sensor where they are counted. Particles with energies lower than the critical energy are bent too much and strike the deflection plates where they are absorbed. Particles with energies greater than the critical energy are not bent enough and enter the light trap where they are absorbed. Electrons and ions are deflected in opposite directions.

4. Charging Influence on Low Energy Data

Spacecraft charging effects charged particle measurements. When a charge is present on the spacecraft, charged particles experience an electrical force due to this charge. They can be accelerated toward the spacecraft, influencing the measured energy and flux, or retarded from the spacecraft, influencing the minimum detectable energy and the particle flux. The UARS charges negatively, thereby attracting positive ions and repelling electrons. The dominate ion at the altitude of UARS is O^{+} .

The UARS charges every orbit. The level of charging is dependent on many parameters and a complete diagnostic study has never been performed. However, certain patterns can be recognized. Early in the mission, spacecraft charging can be characterized by the sharp rise in the potential at sunrise to about -100 V, a decay during the day to about -20 V, and then a slight increase to about -40 V as depicted in Figure 5.

If one examines the characteristic of the plasma at sunrise in more detail, one can see that there remains a slight charge on the spacecraft, more consistent with that residual potential on the Auxiliary Array, see Figure 6. During the penumbra when the scattered light increases, the ion flux appears to follow the shape of the Auxiliary Array current. When full sunlight hits the array, the charging peak seen in the ions is the largest. In Figure 6, the spacecraft reaches about -80 V.

The characteristic of the plasma at sunset reveals more detail as well. Most of the time there is a rise in the spacecraft potential just before sunset as shown in Figure 7. Typically the current and voltage from the Main Solar Array decrease more rapidly than the current and voltage of the Auxiliary Array; however there is usually no indicator of the jump in spacecraft potential at sunset.

Over its lifetime, the UARS has had system failures. The solar array is currently parked and no longer tracks the sun. This has caused the shape of the charging curve to be flatter, but there are often additional charging spikes at sunrise and sunset often occur. The current and voltage patterns through the orbit exhibit a more gradual translation than when the array was rotating. This is depicted in Figure 8.

For MEPS, there are additional electron effects besides the effect of a repelling of charge due to the spacecraft. When spacecraft potentials become high, the local thermal ion plasma environment is accelerated into the detector. This causes a higher ion flux on internal surfaces of Figure 4 than that designed as tolerance. This results in generation of enough secondary electrons that they are able to traverse the deflection region and be counted as high energy electrons. This effect can be seen in Figure 9. The consequence of blindly using MEPS data will cause a large over prediction of the amount of energy deposited in the Mesosphere. For this reason, the MEPS data are ignored by the UARS project during daylight.

5. Pre-Launch Charging Study

Charging of the UARS was taken as a serious problem prior to launch. During UARS design phase, a thorough study of UARS charging was conducted by S-Cubed. They considered two types of charging, solar array driven and auroral driven, and three possible solutions: modify the solar array, provide a grounded conducting area for current collection, and provide a plasma source on the spacecraft. The study concluded that the best solution for dealing with both charging types was a plasma source on the spacecraft (none was included on UARS). Each solution had trade-offs in cost, practicality, and thermal design. Each option was considered and the results show that the solution was not adequate.

The S-Cubed study also found that the spacecraft would be driven to -30 V at sunrise. They used a value of -6 V to be their acceptability criteria. As can be seen in Figure 5, the UARS exceeded the -6 V acceptable limit determined by S-Cubed often. Most of the data from the dayside is thought to be too contaminated for production. There are some cases where useful science data can be retrieved from the day side; however these data must be hand corrected for spacecraft charging effects.

6. Conclusion

During daylight, the UARS spacecraft charged. Just after launch, with a rotating solar array, the characteristic of the spacecraft charging was that it reached the -100 V level on sunrise, decreased potential through the day to about -20 V, and then rose to about -40 V just before sunset. Today, the solar operation is stationary and the spacecraft shows steady level of charging through the day. Charging effects the MEPS instrument, exceeding its level of tolerance to charging effects. Charging effects can be seen in both ion and electron measurements.

7. Figures

Figure 1. Spacecraft Integration. This picture shows the UARS spacecraft during its integration phase at General Electric, the spacecraft contractor. The view is from a position viewing at the side of the spacecraft which includes many of the science instruments. The graphite-epoxy titanium structure serves as the rigid "optical bench" for the arcsecond accuracy spacecraft.

Figure 2. UARS Power System. The solar array is divided into a main solar array and an auxiliary solar array. Power from the main array is fed to the modular power subsystem (MPS) standard power regulator unit (SPRU) to charge the storage batteries for night time operation and support the bus protection assembly (BPA), signal conditioning assembly (SCA), subsystem remote power units (RIU), and power control units (PCU). The remaining main array power is used to control multimission modular spacecraft (MMS) functions such as the modular attitude control subsystem (MACS), communications and data handling (CDH), signal conditioning and control unit (SCCU), and power module (PM-1A) for spacecraft propulsion. Any remaining power is then diverted to the science payloads. This remaining power from the main array is supplemented with power from the auxiliary solar array. The amount of power is controlled by the auxiliary array switch which adjusts and maintains the correct amount of power provided to the payloads.

Figure 3. The UARS Spacecraft Design. This figure depicts the design of the UARS. It shows the location of the science payloads and major engineering components. The low-energy particle detectors are part of the Particle Environment Monitor (PEM), located on both the zenith and nadir booms.

Figure 4. The MEPS Detector. Shown is the major components of the Medium Energy Particle Spectrometer (MEPS) which measures both electrons and ions simultaneously from the energy range of 1 eV to 32 keV. Plasma enters through the entrance aperture in the collimator and encounters an electric field generated across a pair of deflection plates. The correct energy particle is deflected so that it impacts on a channel electron multiplier (CEM) sensor.

Figure 5. Typical Orbital Charging. There are three panels in this figure. The upper panel shows the energy-time spectrum from the 36 degrees ion sensor below 400 eV. The center panel shows the voltage and current from the Auxiliary Array. In the lower panel is shown the voltage and current from the main solar array. The high flux of ions seen in the upper panel is due to the spacecraft being charged negatively and attracting oxygen ions. Ion flux below the charging line represents ion flux which originated from the spacecraft and is returning. These data were taken in November of 1991.

Figure 6. Charging at Sunrise. Shown in the same format as Figure 5, the characteristic of the plasma at sunrise indicates more detail. One can see that there remains a slight charge on the spacecraft, more consistent with that residual potential on the Auxiliary Array. During the penumbra when the scattered light increases, the ion flux appears to follow the shape of the Auxiliary Array current. When full sunlight hits the array, the charging peak seen in the ions is the largest. Here, the spacecraft reaches about -80 V. These data were taken in November of 1991.

Figure 7. Charging at Sunset. Shown in the same format as Figure 5, most of the time there is a rise in the spacecraft potential just before sunset. Typically the current and voltage from the Main Solar Array decrease more

rapidly then the current and voltage of the Auxiliary Array; however there is usually no indicator of the jump in spacecraft potential at sunset. These data were taken in November of 1991.

Figure 8. Fixed Array Charging. The solar array is currently parked and no longer tracks the sun. The shape of the charging curve is flatter, but charging spikes at sunrise and sunset often occur. The current and voltage patterns through the orbit exhibit a more gradual translation than when the array was rotating, as in Figure 5. Data shown here is in the same format as in Figure 5. These data were taken in May of 1997.

Figure 9. Effect on Electrons. Shown in this figure are the energy-time spectrograms over the full MEPS energy range. Here we examine the sunset portion of data from the 21.3 degrees sensor which also shows the same characteristic charging line. During the increase in the charging line just before sunset (0911-0914 UT), one can see an enhancement in the flux at high energies. This enhancement is due to the increased ion flux causing secondary electrons to be emitted within the detector, and these secondary electrons are being detected by the electron sensor.